Restoration of the White Abalone in Southern California: Population Assessment, Brood Stock Collection, and Development of Husbandry Technology. Final Report.

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Abstract

In 2001, white abalone, *Haliotis sorensoni*, became the first marine invertebrate to be listed as an endangered species. A submarine survey of rocky reefs for white abalone at offshore islands and banks in southern California found white abalone at densities three orders of magnitude lower than historically reported. Using the abundance of abalone at different locations and the amount of potentially suitable habitat at these locations, we conservatively estimate that 3,000 individuals (or < 2.3 metric tons) remain in California (most on the offshore banks) compared with the total combined commercial landing of >280 metric tons. An estimate of the number of white abalone in Mexico (based on rough estimates of suitable habitat) only added another 200-2,000 animals to the total abundance for the species. Abalone were associated with *Laminaria farlowii* (an alga) and occurred on relatively large rocks (with a variety of algal/invertebrate cover), usually near the rock-sand interface. We were able to collect several white abalone and hold them in captivity until they were ready to spawn. Spawning resulted in settled juveniles that are presently under culture.

Executive Summary

Between 1969 and 1977, legal fishing reduced white abalone density in the United States by several orders of magnitude. The National Marine Fisheries Service listed white abalone as endangered in 2001. Lack of information on present distribution and size structure makes it difficult to assess alleged impacts of fishing on this species. An even greater ignorance of habitat use and husbandry precludes the ability to develop restoration strategies.

Our first objective was to describe the distribution, abundance and habitat characteristics of the remaining white abalone (*Haliotis sorensoni*) populations in southern California, USA to (1) estimate the current abundance of white abalone, (2) assess whether white abalone demographics have changed since early studies in the 1980s and (3) obtain basic natural history information that may be useful in managing and restoring this species. Our second objective was to develop technology for husbandry. This included evaluating collecting and handling techniques, developing holding protocols, establishing spawning protocols, determining successful settling methodology and finding ways to efficiently raise large numbers of juveniles. Kevin Lafferty (USGS) and Dan Morse (UCSB) served

as principle investigators on the award to UCSB. Tom McCormick served as the lead on the subcontract with CIMRI.

To better understand habitat use, we conducted survey dives from 9 to 25 October, 1999 using the Research Submarine DELTA and the Research Vessel VELERO IV in waters off southern California over rocky substrate at appropriate depths where recreational and commercial divers indicated white abalone populations were once abundant. Several agencies assisted with field surveys (USGS, NPS, NMFS, CDFG, UCSD, UCSB). Dives consisted of a scientist observer and a submarine pilot and typically lasted 2 hours. We identified each abalone or empty abalone shell to species and then reported it to the support vessel and estimated relative densities in terms of abalone per 5-minute search time and area searched. We found white abalone to be at densities three orders of magnitude lower than historically reported. Using the abundance of abalone at different locations and the amount of potentially suitable habitat at these locations, we conservatively estimate that 3,000 individuals (or < 2.3 metric tons) remain in California (most on the offshore banks) compared with the total combined commercial landing of >280 metric tons. An estimate of the number of white abalone in Mexico (based on rough estimates of suitable habitat) only added another 200-2,000 animals to the total abundance for the species. Abalone were associated with *Laminaria farlowii* (an alga) and occurred on relatively large rocks (with a variety of algal/invertebrate cover), usually near the rock-sand interface.

SCUBA divers with the California Department of Fish and Game searched areas of potential white abalone habitat within safe diving depths. They delivered 9 animals to holding facilities at UCSB and 9 to the Channel Islands Marine Resource Institute. In both Fall 2000 and later winter 2001 all animals were picked and examined for determination of sex and gravidity and were photographed for documentation. All animals were found to be healthy and all had gonads sufficiently large as to be candidates for spawning. No spawning occurred, suggesting that induction of spawning in the white abalone in the fall may not be possible.

On April 23, 2001 two females and one male were spawned, producing six million fertilized eggs. The eggs were hatched and raised at a temperature of 11 - 13ºC for eight days until competent to settle on May 1. Survival from egg to settlement was 60 %. 3.2 million larvae were settled on microalgae in outdoor tanks using standard large-scale cultivation techniques. Post-settlement and early juvenile abalone were raised at temperatures of 13 to 15ºC. At 71 days a survey of growth and survival indicated that average survival from settled larvae was 7% (weighted average of 7 tanks). Average length at 71 days was 2.28mm, with growth averaging 32 µm per day. At 144 days post-spawn, survival was 6% and the average shell length was 6.2 mm . Juvenile abalone were then fed macro-algae. By October 29, at an age of 6 months old, the juvenile white abalone averaged 8 mm in length. Survival from settlement has dropped slightly to 5%. This is well within the range expected for mass cultivation of juvenile abalone.

The goals of the project were fully achieved. We have submitted a scientific paper for peer review and presented several scientific talks. The only significant modification to

our project was related to the lack of available broodstock in the wild. This delayed our efforts and limited the number of animals we could spawn. Future work, given available funding, will focus on developing commercial-scale grow out techniques and outplanting strategies.

Purpose

The problem addressed

Five of the seven abalones in California are sufficiently large and were previously dense enough to have supported a valuable commercial and recreational fishery, presumably aided by the increase in their densities in the absence of sea otters. As in other abalone fisheries (Breen 1986, Tegner 1989), overfishing has been implicated in the decline of California abalone (Karpov et al. 1998). Currently, the only permitted abalone take in California is by recreational free-diving and shore-picking for red abalone north of San Francisco (Karpov et al. 1998).

White abalone occur between Punta Abreojos in Baja California, Mexico and Point Conception, California, USA. Santa Catalina and San Clemente Islands were the reported centers of abundance (Cox 1960, Leighton 1972). Historically, they have been most common at depths between 25-30 m where they feed on attached and drift algae (Tutschulte 1976). Tutschulte (1976) suggested that white abalone could survive in shallow water but that competition from shallow-water abalone species and predation from octopus (and formerly sea otters) limited this thin-shelled and exposed abalone to deep water. White abalone mature in 4-6 years at a size of 9-13 cm and have a 1:1 sex ratio (Tutschulte and Connell 1981). Adults reach about 20-25 cm in length in southern California (males tend to be larger) and maximum size decreases in more southern latitudes (Hobday and Tegner 2000). Hobday and Tegner (2000) concluded that between 1969 and 1977 legal fishing reduced white abalone density in the U.S. by several orders of magnitude; in Mexico, limited information suggests that impacts occurred later and that appreciable, though declining, numbers of white abalones were landed into the 1990s. Hobday and Tegner (2000) dismissed habitat destruction, predation, or disease as reasons for declining populations. The National Marine Fisheries Service listed white abalone as an endangered species in 2001 (National Oceanic and Atmospheric Administration 2001).

Lack of information on present distribution and size structure makes it difficult to assess alleged impacts of fishing on this species. Even greater ignorance of habitat use and husbandry precludes the ability to develop restoration strategies.

Objectives

Our first objective was to describe the distribution, abundance and habitat characteristics of the remaining white abalone (*Haliotis sorensoni*) populations in southern California, USA to (1) estimate the current abundance of white abalone, (2) assess whether white

abalone demographics have changed since early studies in the 1980s and (3) obtain basic natural history information that may be useful in managing and restoring this species.

Our second objective was to develop technology for husbandry. This included evaluating collecting and handling techniques, developing holding protocols, establishing spawning protocols, determining successful settling methodology and finding ways to efficiently raise large numbers of juveniles.

Approach

Field work

We conducted survey dives from 9 to 25 October, 1999 using the Research Submarine DELTA and the Research Vessel VELERO IV in waters off southern California, including the Santa Cruz, Anacapa, Santa Barbara, Santa Catalina and San Clemente islands and at the Osborn, Farnsworth, Tanner and Cortes offshore banks. As on previous dives (Davis et al. 1996, 1998), we surveyed over rocky substrate at appropriate depths where recreational and commercial divers indicated white abalone populations were once abundant.

Dives consisted of a scientist observer and a submarine pilot and typically lasted 2 hours. In areas without potential abalone habitat (e.g., sandy bottom), the submarine surfaced and moved to a new location after a 10-30 minute search period. In appropriate habitat (rocky substrate between 30 and 70 m depth), the pilot moved slowly close to the substrate and the observer searched for live abalone and abalone shells. During surveys, a Hi8 video camera and light mounted to the starboard side of the submarine recorded part of the field of view, time, date and depth. The audio portion of the videotape recorded pilot and observer descriptions of the animals, plants and habitat seen. Two parallel lasers set at a distance of 20 cm projected spots in the video's field of view, allowing us to measure items from the video. An externally mounted 35 mm still camera with a strobe and digital cameras aimed through the portholes provided photographs of selected subjects.

Large white abalone are emergent, often attached to the tops and sides of rocky substrate (Tutschulte 1976), making them relatively easy to locate underwater. We identified each abalone or empty abalone shell to species and then reported it to the support vessel. We often attempted to retrieve shells. We did not collect live animals because of the limited dexterity of the submarine's arm and its potential to damage animals. We usually photographed the live abalone we encountered and then made a more thorough inspection of the immediate area for additional abalone. For this reason, we tended to spend more time at locations where abalone were abundant.

A sonar tracking and ranging device integrated into the support vessel's differential geographic positioning system (GPS) provided a geographic position of every abalone located. It also tracked the position of the submarine every 30 seconds. We calculated the distance traveled by the submarine every 30 seconds by converting the sequence of positions into line segments, the lengths of which we measured as the square roots of the

sums of the squared differences of the UTM latitudes and longitudes. We identified and eliminated aberrant GPS positions (by flagging distance values that exceeded two standard deviations from the mean distance traveled). We calculated the linear distance of the dive as the sum of the 30-second segments. To estimate the area searched, we considered that the observer's field of view was 4 m^2 (a conservative estimate).

Following each dive, the observer reviewed the video and entered observations into a data form for later inclusion into a Microsoft Access database. At five minute intervals, we recorded algal cover, including a list of the dominant species, the number of abalone by species, the number of abalone shells, by species, the depth, substrate type, substrate relief and a subjective determination of whether the area appeared to be suitable habitat for abalone.

These data provided an estimate of relative densities in terms of abalone per 5-minute search time. We compared the relative density among our locations to better understand the present distribution of abalone. By noting the relative density of animals per search effort at a particular depth, we constructed depth-frequency histograms for comparison with known former depth ranges. We also noted any animals with neighbors within 2 m.

We also estimated a maximum absolute density, abalone per hectare (ha), based on the estimated area of suitable substrate searched. This density is probably an over estimate for two reasons: our actual field of view effort was likely greater than 4 m^2 and we focused our efforts in good abalone habitat. Therefore, actual white abalone densities could be lower than we report. We multiplied the density of abalone at each location by the amount of potential white abalone habitat at that location (as per Davis et al. 1998) to provide a coarse estimate of the abundance of white abalone in southern California. We compared our density estimates with previous estimates of density at Santa Catalina Island (very coarse estimates by Tutschulte 1976).

We estimated shell lengths from a VHS copy of original videotapes. We measured the greatest shell length and distance between the lasers on the monitor screen at the point where the lasers were closest to the abalone. We then converted the two lengths to the estimated shell length. In cases where the shell was at an angle to the video, we corrected our estimate by orienting a hand-held white abalone shell to a similar angle and estimating the difference between the apparent shell length and the true shell length. We used these data to construct size-frequency histograms.

In addition to noting the density of abalone across sites and depths, we characterized the locations where abalone occurred at coarse and fine spatial scales. We first used a stepwise approach to construct a multivariate statistical model that best predicted abalone abundance per 5-minute observation period. Then, to determine if abalone were selective in their use of rocks within a habitat, we compared the characteristics of each occupied rock with the nearest unoccupied rock. For each abalone, we estimated the maximum rock dimension and distance to nearest rock from the video according to five length classes (0-40, 41-80, 81-120, 121-160, and >160 cm.). We recorded the presence of neighboring red sea urchins, *Strongylocentrotus franciscanus,* (if they were within 0.5 m

of an abalone). We recorded the presence of adjacent algae (defined as within 0.2 m of an abalone). Finally, to quantify the position of an abalone on its rock, we estimated the distance (to the nearest 10 cm) from the shell margin down to the sand/rock interface and up to the rock apex. We also made feeding observations for each abalone from the video. We considered an abalone to be feeding if there was fleshy algae trapped under the shell margin.

To place our observations in a historical context, we conducted an oral history with Buzz Owen who dived commercially for abalone from 1959 to 1964 in the region around Point Conception, San Nicolas Island and the northern Channel Islands. Buzz Owen began diving and collecting abalone shells in 1949. During the years he fished, *H. sorenseni* landings were not specifically tracked and counts were added to the "pink abalone" category. This makes his recollections of white abalone from this period particularly useful.

Husbandry

We collected 18 white abalone from Santa Catalina Island. SCUBA divers searched areas of potential white abalone habitat within safe diving depths. To facilitate capture, they waved a frond of kelp directly in front of the abalone. If the abalone had not been previously disturbed, the smell or touch of the kelp would cause the abalone to rear up in a food capture stance where it can be easily pried by hand from the rock. If the surface of the rock is smooth, and the diver experienced, it was possible to remove the abalone with no or minimal damage using an abalone iron. Divers avoided exposing collected abalone to thermal shock on the trip to the surface by placing each abalone in a sealed plastic bag filled with seawater. Abalone were not kept in the bag for more than 15- 20 minutes because the animal would otherwise consume the available oxygen. Once on board the vessel, we kept abalone cool at temps between 13 to 18°C. with a cool ice chest or, where possible, with flowing, cool seawater and oxygen. We tagged abalone immediately upon bringing them onboard ship with a stainless steel washer (approximately 5/8" in diameter) stamped with an identifying number held in place with stainless steel wire passed through the top-most respiratory pores. The wires were then twisted together so that the wire was tight against the shell and did not move. We trimmed the excess wire and bend the end against the shell so there was no sharp projection. After tagging, the shell length, total weight, and sex were recorded as were the location of site, depth, bottom temperature, bottom type, types of kelp observed, the person who collected the abalone and any other relevant details.

We took tissue samples to provide valuable genetic information about the population structure of the white abalone and track lineage in hatchery raised stocks. With a pair of tweezers we grasped one of the epipodal tentacles on the sides or posterior of the animal. While gently pulling the tentacle we used a nail clipper to cut the tentacle 1 – 2 mm from its base. We then placed the tentacle in a microfuge tube with 1 - 2 ml of a high salt buffer 5XNET, pH 8 solution. This solution was composed of 2.5 Molar NaCl, 0.25 Molar EDTA, 0.25 Tris pH 8. We then sealed the top of the tube and recorded the animal number, location, and date on the tube label and refrigerated the tube.

We carefully packed the animals for transport to holding facilities. In the shipping bag (2' X 2'6", 30 gallons or larger), we immersed three pieces of foam rubber sheet (18" X 18", or appropriate size to fit the plastic bag) into the cold seawater of the holding tank and squeezed the excess water from two pieces of foam. After removing abalone from the temporary holding tank , we drained excess water for 30 seconds and placed the abalone right side up on the foam (several abalone can be placed side by side on the foam). Finally, the third piece of damp foam was placed over the abalone. The trips were shorter than 8 hours so we loosely closed the plastic bag with a rubber band so that a small amount of gas exchange would occur. We kept the abalone cool with frozen gel packs at a ratio of: 2.5 kg of abalone to 1 kg of frozen gel pack placed between the bags and the cooler wall, being careful that the frozen gel did not touch the abalone by wrapping the gel packs in thick newspaper

Animals were brought to holding facilities at UCSB and the Channel Islands Marine Resource Institute. Upon arrival of the abalone at the holding facility, we assessed the health and spawning condition of the abalone. The soft tissues of the foot and epipode were examined for any nicks, cuts or abrasions resulting from collection. Any findings were noted on a data sheet that contained the abalone number, and the date and location of collection. The total weight and shell length were noted along with information about the appearance of the shell. We photographed animals on arrival. The gonad index (GI) of each abalone was noted. After abalone were placed in the holding systems, we checked the gonad index no more often than once a month since the process of removing the abalone from the tank and handling it is stressful and will inhibit growth.

Newly acquired abalone were held separately from those already in the facility for a period of six weeks. This provided enough time for the new abalone to undergo an antibiotic treatment for withering syndrome. During the quarantine period, all equipment was washed with 100 ppm chlorine and rinsed with seawater after use in the new abalone tanks. Technicians washed hands after working with the new abalone. Dr. Caroline Friedman, pathologist for the California Department of Fish and Game, developed an antibiotic treatment for the control of withering syndrome in white abalone. Following delivery to the holding facilities, all abalone were inoculated as per Dr. Friedman's protocol. If shells were heavily infested with boring organisms such as polychaetes, mollusks or sponges, we treated the outer shell to eliminate these hitchhikers, sealing the outer shell with wax.

Holding conditions mimicked day to day and seasonal variations in the natural habitat. Consideration was given to control temperature, dissolved oxygen, feeding, waste removal, bacteria, lighting conditions, and handling methods. Maximum holding temperature was set as 18°C. Temperatures as low as 10°C were used to stimulate gonad maturation. We fed animals *ad libitum* once or twice a week depending upon the rate of consumption and condition of the kelp. Prior to feeding to abalone, kelp was immersed for 5 minutes in freshwater to remove unwanted epibionts and reduce the introduction of pathogenic bacteria, such as rickettsia. We handled abalone with great care since their tenacious hold on the substrate and tenderness make a combination that may result in nicks or cuts when in the hands of an unpracticed worker. To remove abalone from the substrate, we used a plastic kitchen spatula with a wide blade and thin profile. Anesthesia was used when animals had to be handled intensively.

Project Management

Kevin Lafferty (USGSS) and Dan Morse (UCSB) served as principle investigators on the award to UCSB. Tom McCormick served as the lead on the subcontract with CIMRI. Kevin Lafferty (USGS) worked with UCSB staff to coordinate reports and budgeting. Commercial crews of the RV Delta and the RV Velero IV assisted with the field work. Knowledgeable commercial and recreational divers (Jon Hardy, James McClellan, Buzz Owen, Cal Parsons and Bob Shea) told us where they had seen white abalone. David Kushner (NPS) interviewed Buzz Owen. Kevin Lafferty (USGS), Gary Davis (NPS) John Butler (NMFS), Pete Haaker (CDFG) David Kushner (NPS), Dan Richards (NPS) Ian Taniguchi (CDF&G) M. J. Tegner (UCSD), Diane Brooks (NPS), John Brooks (NPS), Eric Hanauer, Neal Hooker (UCSB), Kon Karpov (CDFG) and Dan Morse (UCSB) volunteered their time to look for white abalone in the submarine. Mike Behrens (UCSB) scored video tape and helped Kevin Lafferty (USGS) analyze data. Ian Tanaguchi (CDFG), Pete Haaker (CDFG), and David Kushner (NPS), Dan Richards (NPS) and John Ugoretz (CDFG) collected broodstock. Tom McCormick (CIMRI), Dan Morse (UCSB), Neil Hooker (UCSB), and Bonnie Bosma (UCSB) developed husbandry techniques with the advice of Pete Haaker (CDFG), Carolyn Friedman (CDFG), Shane Anderson (UCSB), and Mia Tegner (UCSD).

Findings

Field work

We made seventy dives in 1999, 58 of which were on suitable abalone habitat. These dives represented 76 hours of bottom time over 143,778 m of submarine track and an estimated 57.5 ha of suitable habitat. We found 157 live white abalone. The average density was, therefore, 2.7 white abalone per ha of white abalone habitat, ranging from 0-9.8 abalone/ha. Because density and sampling effort varied strikingly among locations, it is more appropriate to calculate density on a location by location basis. White abalone were most abundant at Tanner and Cortes banks and rare everywhere else, except at Osborn Bank where we did not find them.

It is difficult to make direct density comparisons with past records of fisheries independent data because so little baseline information exists. However, at Santa Catalina Island, Tutschulte (1976) reported a density of 2,300 white abalone per ha while we found 1 per ha at Santa Catalina. Densities in Mexico in 1969 and 1970 were 1,000 per ha (Guzman del Proo 1992). White abalone were historically thought to be less abundant in Mexico than at Santa Catalina and San Clemente Islands where we found 1 abalone per ha.

Although we lack data for the northern Channel Islands and the mainland coast of southern California, white abalone have historically been less abundant in these locations than at the southern offshore islands. To calculate an estimate of abundance in these areas, we assumed that the density of white abalone (per available habitat) in these areas was equivalent to what we found at Anacapa Island (0.79 abalone per ha). In total, we estimated that fewer than 3,000 white abalone remain in California, more than 80% of which are located on the offshore banks. Although we know little about white abalone populations in Mexico, if densities there now range from the present densities at San Clemente Island (0.94 abalone per ha) to Tanner Bank (9.8 abalone per ha), there are only about 200-2,000 additional individuals in Mexico (given the estimate of potential white abalone habitat in Mexico from Davis et al. 1998).

White abalone were previously recorded to be most common between 25-30 m, but none occurred this shallow, and most were appreciably deeper (> 40 m, average depth of white abalone was 50 m (sites pooled) or 49 m (locations averaged). Because much of the search effort tended to be slightly shallower than the mean depth distribution of abalone (we found little appropriate habitat at deeper depths), we feel we adequately sampled the shallow portion of the white abalone's present distribution. The depth distribution of white abalone did not vary significantly among locations nor did it differ between remote and accessible sites. Due to the large number of abalone found on the offshore banks, it was possible to statistically compare the mean depth at Cortes Bank with Tanner Bank. The mean depth at Cortes (51 m) was slightly, but significantly, deeper than at Tanner Bank (47 m, $P < 0.05$). One problem with comparing mean depths of abalone among sites was that variation in the search effort at different depths could affect the mean reported depth of abalone. To account for this, we standardized density by search effort at a particular depth to create a distribution of density by depth. Pooling across sites, white abalone were densest between 43 and 60 m. They did not occur deeper than 66 m or shallower than 31 m. A comparison of the density by depth distribution for Tanner Bank and Cortes Bank showed that abalone were indeed deeper at Cortes Bank than at Tanner Bank. In fact, at Cortes Bank, abalone were at the deepest depths surveyed.

Few white abalone (20%) had neighbors within 2 m. There were 14 pairs (two at Santa Barbara Island, four at Farnsworth, five at Tanner and three at Cortes) and one group of four at Cortes Bank. This distribution suggested that only 20% (data pooled) to 24% (locations averaged) of abalone were in close enough proximity to mate at the time we observed them. Home scars were present, suggesting that some abalone had stayed in the same spot for a considerable length of time. On one occasion, we observed an abalone

travelling across the sand, indicating that they may be able move sufficient distances to find mates.

The mean length, measured as the maximum length of the shell, of measurable white abalone was 14.8 cm (SD = 2.63, N = 86). Mean length varied moderately, but significantly among the three sites with sufficient sample sizes to compare (with Tanner Bank (14.1 cm, SD = 2.3, N = 39) having smaller animals than Cortes (15.7 cm, SD = 2.8, N = 19) and San Clemente (15.6 cm, SD = 2.9, N = 15) (P = 0.04, ANOVA). The higher proportion of small individuals at Tanner Bank (the highest density location) suggests a positive association between density and recruitment.

Analyses of the video provided insights into white abalone habitat, habitat choice and behavior. After controlling for depth and location, white abalone were not significantly associated with the algae *Pelagophycus porra* or *Eisenia arborea* or the amount of rock (relative to sand) in the habitat (in interpreting the lack of association with rock it is important to consider that areas without rock have no abalone but these were excluded from the analysis). The best model (R-square = 0.23) found that white abalone were most dense in areas where the rock had low relief ($P < 0.0001$) and relatively high cover of *Laminaria farlowii* ($P = 0.0003$). It also found that density increased with distance from port (which was used as a covariate, $P = 0.0365$). Rocks with white abalone were larger than the nearest rock without abalone (Paired T, $P = 0.002$). There was no significant difference in the algal cover or presence of red urchins on neighboring rocks with and without abalone ($\chi 2 > 0.05$, in all cases). White abalone were not randomly distributed over the vertical surface of their rock ($\chi 2 = 19.342$; $P < 0.0001$). They were most often close to the sand/rock interface. Individuals that were feeding were more likely to be near urchins than abalone that were not feeding ($\chi 2 = 9.718$; $P < 0.003$). Abalone responded to the video lights with increased activity and a tendency to move away from light.

In the oral history, Buzz Owen noted that at Anacapa and the east end of Santa Cruz islands, *H. sorenseni* comprised about 25% of the "pink" abalone catch. Most of these were taken at depths less than 25m. His log books noted the following locations where he saw and or took *H. sorenseni:* Santa Catalina Island: East of Cat Harbor (3-22 m depth), Santa Barbara Island: near Southeast Sea Lion, San Nicolas Island: east end sand spit, Anacapa Island: Admiral's Reef (<25 m depth), offshore Admiral's Reef, Fish Camp (3-5 m depth!), east of Fish Camp (6-8 m depth), Cat Rock (20-25 m depth), north side of west end (< 23 m depth), Santa Cruz Island: Morse Pt. To San Pedro Point, west of Gull Island, Coches Prietos, Yellowbanks (common, < 18 m depth), east of Sandstone Point (18-19 m depth), mainland Los Angeles County: Portuguese Bend (Palos Verdes Penninsula), and mainland Santa Barbara County: Coal Oil Point (scattered in 8-18 m depth), 2 km west of Coal Oil point (3-10 m depth), Canby's Reef (Santa Barbara Harbor), 500-600 m off the Santa Barbara Harbor Breakwater (6-7 m depth, also red-white hybrids), Table Rock (near Naples Reef), 10 km east of Point Conception and St. Augustine Point.

Owen's observations were not limited to fishing commercial abalone. While working in an aquaculture facility at Pigeon Point, Owen had no problems getting *H. sorenseni* to spawn, but was never able to get larvae to settle. Owen also specifically looked for

juvenile abalone in the wild. On the dozen or so occasions when juvenile or small adult *H. sorenseni* were observed by him or others, there were typically just a few and at a few sites (Admiral's Reef, Yellowbanks, Coal Oil Point to Naples Reef). Owen recalled that *Haliotis kamtschatkana-assimilis*, a smaller, unfished abalone species, was formerly common, especially near Pt. Conception and on the south side of San Miguel. To our knowledge, a live *H. kamtschatkana-assimilis* has not been observed in the last decade, though we recently collected a fresh juvenile *H. kamtschatkana- assimilis* shell off Yellowbanks, Santa Cruz Island and live adults along the mainland of Santa Barbara County. Owen also noted a decline in *Haliotis walallensis* over the past decade (north of Point Conception). Neither species is fished to any appreciable extent.

Husbandry

The California Department of Fish and Game delivered nine adult white abalone collected from waters off southern California to CIMRI and nine to UCSB. Of these abalone, three at CIMRI died within a short period following collection (12/1/00, 12/6/00, and 12/13/00) probably the result of cuts that were observed on the foot. Another abalone died on 3/23/01. This animal had crawled above the water line of its holding tank. A tight-fitting lid prevented the animal from crawling out of the container, but it still became desiccated and died. Broodstock animals were administered doses of Oxytetracycline to treat for a rickettsia-like-protozoan (RLP) that has produced withering syndrome in other species of abalone in southern California. Normally this calls for three treatments every other day, repeated every other week for six weeks. For the white abalone only, two series of three doses were administered from 11/27/00 to 12/13/00. The treatments were stopped at that point to eliminate the possibility that the extra handling or treatments were causing additional stress to the animals and resulting in mortality. RLP was found in none of the dead abalone that were sent to Dr. Friedman at the Bodega Marine Laboratory for histological examination.

At CIMRI, white abalone broodstock were held in a partially recirculating system with temperature control to bring the wild abalone broodstock to spawning readiness in the broodstock holding systems. In an effort to balance the nutritional needs of the abalone, a mixed diet of brown algas: Giant Kelp (*Macrocystis*); and Feather Boa Kelp (*Egregia*) was supplemented with cultured red algae, Pacific dulse (*Palmaria mollis*). The dulse, cultivated in the water from the recirculating system, served a secondary function as a biofilter, absorbing nitrogen and phosphorus excreted by the abalone.

At UCSB, white abalone broodstock were maintained in a circular 400 gallon fiberglass tank, which is both recirculating and flow-through. Both ambient and chilled sea water are provided at all times and the temperature is maintained between 14º C and 16ºC year around. The diet was principally the giant kelp *Macrocystis pyrifera* that was supplemented periodically with the red algae *Erythrophyllium delesserioides, Gelidium robustum,* and *Gigartina exasperata.* Broodstock rapidly healed from the cuts obtained from being picked in the wild as well as continued to increase in gonadal bulk, indicating white abalone do well under these conditions.

Tissue samples of the epipodial tentacles were collected in duplicate from each abalone for genetic characterization. This procedure was performed per the protocol and materials provided by Tom McCormick of CIMRI (Channel Islands Marine Resource Institute). The samples were stored refrigerated until they were sent to Dr. Ron Burton at Scripps Institute of Oceanography for analysis.

In both Fall 2000 and later winter 2001 all animals were picked and examined for determination of sex and gravidity and were photographed for documentation. All animals were found to be healthy and all had gonads sufficiently large as to be candidates for spawning.

Spawning of the white abalone in the wild has been reported to be in the winter to early spring. Since we found all of our broodstock to be sufficiently gravid to be potentially spawnable by late fall of 2000, we decided to attempt to spawn them in early November. Four animals were selected, two males and two females, and were placed individually in tubs with 15ºC sea water. The technique of Morse, et al. developed for induction of spawning of the red abalone was used. The sea water in which the animals are held is made moderately basic (pH 9) by the addition of 2 M Tris Base followed by the addition of freshly diluted 6% hydrogen peroxide. No spawning occurred, suggesting that induction of spawning in the white abalone in the fall may not be possible.

On April 23, 2001 two abalone from CIMRI were transported to UC Santa Barbara for spawning. The result was a successful spawn of two females and one male. Six million fertilized eggs were produced. On the same day the eggs were transported to the Ormond Beach Research Laboratory, in Oxnard which is working in conjunction with CIMRI. The eggs were hatched and raised at a temperature of 11 - 13ºC for eight days until competent to settle on May 1. Survival from egg to settlement was 60 %. On May 3, an additional 255,000 larvae were transported from UCSB to CIMRI where they were settled on both microalgae and Pacific dulse in a settling experiment. Abalone and algae were raised in a recirculating system under artificial lighting.

At the Ormond Beach Mariculture Laboratory a total of 3.2 million larvae were settled on microalgae in outdoor tanks using standard large-scale cultivation techniques. Post-settlement and early juvenile abalone were raised at temperatures of 13 to 15ºC. At 71 days a survey of growth and survival indicated that average survival from settled larvae was 7% (weighted average of 7 tanks). Average length at 71 days was 2.28mm, with growth averaging 32 um per day.

Abalone were again measured on September 13, 2001 (144 days post-spawn). At that time the average shell length was 6.2 mm. Survival from settlement to 144 days was 6%. Weaning of juvenile abalone from a diet of diatoms to diet of macro-algae was begun on September 27. Juvenile abalone were fed cultivated Pacific dulse. The next day abalone were observed feeding on the dulse and associated diatoms. In subsequent days, abalone were also fed *Macrocystis*, *Egregia* and *Gracilariopsis.* We were surprised by the extent that abalone preferred Egregia because this is a shallow water alga. This lends supports to the observations by Buz Owen that white abalone formerly occurred in shallow areas.

By October 29, at an age of 6 months old, the juvenile white abalone averaged 8 mm in length. Survival from settlement had dropped slightly to 5%. This is well within the range expected for mass cultivation of juvenile abalone. By October the juvenile abalone were consuming both micro-algae and all the macro-algae named above.

Experiments intended to determine the relationship between temperature, alga type and growth rate are ongoing. CIMRI is finalizing a second facility for grow-out, reducing that chance that a system failure will kill all the captive animals. Future work, given available funding, will focus on further developing commercial-scale grow out techniques and outplanting strategies.

Evaluation

The goals of the project were fully achieved. The only significant modification to our project was related to the lack of available broodstock in the wild. This delayed our efforts and limited the number of animals we could spawn.

Dissemination of Project results:

The following paper was submitted to Marine Ecology and is in review: Lafferty, K.D., M. D. Behrens, G. E. Davis, P. L. Haaker, D. Kushner, D. V. Richards, I.K. Taniguchi, M. J. Tegner. Abundance and habitat of endangered white abalone, *Haliotis sorensoni*

The following presentations were delivered at scientific meetings:
Haaker, P. L. , D. V. Richards, K. D. Lafferty and J. Butler. 1999. Aspects of the ecology of white abalone, *Haliotis sorenseni.* Western Society of Naturalists Meeting. Monterey, CA.

Richards, D. V., P. L. Haaker, J. Butler, K. D. Lafferty 1999. White abalone, living on the edge. Western Society of Naturalists Meeting. Monterey, CA.

In addition, many of our results were discussed at a symposium on white abalone at the 2001 Cal Cofi meetings.

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